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DRAFT FOR REVIEW

Great Bay Nitrogen Non-Point Source Study

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Definitions of Acronyms, Important Terms, and Units

Acronyms

GBNNPSS: Great Bay Nitrogen Non-Point Source Study
TN: Total Nitrogen
NLM: Nitrogen Loading Model
ELM: Estuarine Loading Model
WWTF: Municipal Wastewater Treatment Facility
HUC12: 12-Digit Hydrologic Unit Code watershed
DES: New Hampshire Department of Environmental Services
PREP: Piscataqua Region Estuaries Partnership
USEPA: U.S. Environmental Protection Agency
USDA: U.S. Department of Agriculture
USGS: U.S. Geological Survey

Important Terms

Estuary: An estuary is a partially enclosed body of water along the coast where freshwater from rivers and streams meets and mixes with salt water from the ocean.

Great Bay Estuary: The body of water beginning at the confluence of the Piscataqua River with the Atlantic Ocean and extending to the head-of-tide dams on Winnicut, Squamscott, Lamprey, Oyster, Bellamy, Cocheco Salmon Falls, and Great Works Rivers. The Great Bay Estuary covers approximately 13,440 acres (21 square miles).

Hampton-Seabrook Estuary: The body of water beginning at confluence of the Hampton River with the Atlantic Ocean and extending to the head-of-tide on the Taylor, Blackwater, Browns, and Hampton Falls Rivers. The Hampton-Seabrook Harbor Estuary covers approximately 1,227 acres (1.9 square miles).

Airshed: An airshed is a geographic area where air pollutants from sources "upstream" or within the area flow and are present in the air. Airsheds cross county, state, and national boundaries.

Watershed: A watershed is the area of land where all of the water that drains off of it goes into the same water body. Watersheds come in all shapes and sizes. They cross county, state, and national boundaries.

Great Bay Estuary Watershed: The area of land where all of the water that drains off of it goes into the Great Bay Estuary. The Great Bay Estuary watershed covers approximately 655,189 acres (1,023 square miles).

Piscataqua Region Watershed: The area of land where all of the water that drains off of it goes into either the Great Bay Estuary, Hampton-Seabrook Estuary or directly in to the Atlantic Ocean along New Hampshire's coast. The Piscataqua Region watershed covers approximately 695,037 acres (1,086 square miles).

HUC12 Subwatershed: A small watershed covering typically 10,000 to 40,000 acres. The USGS has assigned Hydrologic Unit Codes (HUC) from 2 to 12 digits long to watersheds across the country. A HUC12 subwatershed is the smallest watersheds in the USGS system and is denoted with a 12-digit code.

Atmospheric Deposition: The process by which a pollutant in the atmosphere falls to the land or surface waters through either wet or dry deposition. Wet deposition occurs when the pollutant is contained in rain or snow. Dry deposition occurs when the pollutant is attached to aerosols that fall to the earth.

Chemical Fertilizer: Any of a large number of organic and synthetic materials, spread on or worked into soil to increase its capacity to support plant growth.

Managed Turf: Grass that is actively managed for use as golf courses, parks and sports fields.

Connected Impervious Area (CIA): Impervious surfaces from which runoff flows directly into municipal storm sewers and surface waters without any opportunity to infiltrate. Also known as Directly Connected Impervious Area or Effective Impervious Area.

Disconnected Impervious Area (DIA): Impervious surfaces from which runoff flows onto lawn or natural vegetation areas where it can infiltrate.

Septic System: An on-site wastewater treatment system that typically consists of a settling tank and a leach field to treat and inject sewage into the ground. Septic systems are typically used for residences in rural areas.

Wastewater Treatment Facility: A facility that treats wastewater from municipal sewer systems in urban areas.

Delivered Load: The amount of a pollutant (e.g. nitrogen) that is delivered from a watershed to the estuary. The delivered load is the initial load that enters a watershed minus the amount of the pollutant that is lost during transport to the estuary.

Units

lb/yr or lb N/yr: Pounds (of nitrogen) per year
lb/ac or lb N/ac: Pounds (or nitrogen) per acre
lb/ac/yr or lb N/ac/yr: Pounds (of nitrogen) per acre per year
lb/1000 ft^2 or lb N/1000 ft^2: Pounds (of nitrogen) per one thousand square feet
tons N/ac: Tons (of nitrogen) per acre
Acres/home: Acres per home

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Executive Summary

The Great Bay Estuary is 21 square miles of tidal waters located in southeastern New Hampshire. It is one of 28 "estuaries of national significance" established under the Environmental Protection Agency's National Estuary Program. In 2009, most of this estuary was placed on New Hampshire's 303(d) list for impairments associated with total nitrogen (hereafter "nitrogen"). Specifically, low dissolved oxygen, macroalgae blooms, and declining eelgrass habitat have been observed in the estuary (DES, 2012).

Sixty-eight percent of the nitrogen that ends up in the Great Bay Estuary originates from sources spread across the watershed rather than direct discharges from point sources, such as municipal wastewater treatment facilities (DES, 2010; PREP, 2013). These sources of nitrogen are called non-point sources and consist of atmospheric deposition, fertilizers, human waste disposed into septic systems, and animal waste. The purpose of this study is to determine how much nitrogen each non-point source type contributes to the estuary. The nitrogen loads from municipal wastewater treatment facilities have been reported elsewhere (DES, 2010; PREP, 2013) and, therefore, are not included in this study except to provide context.

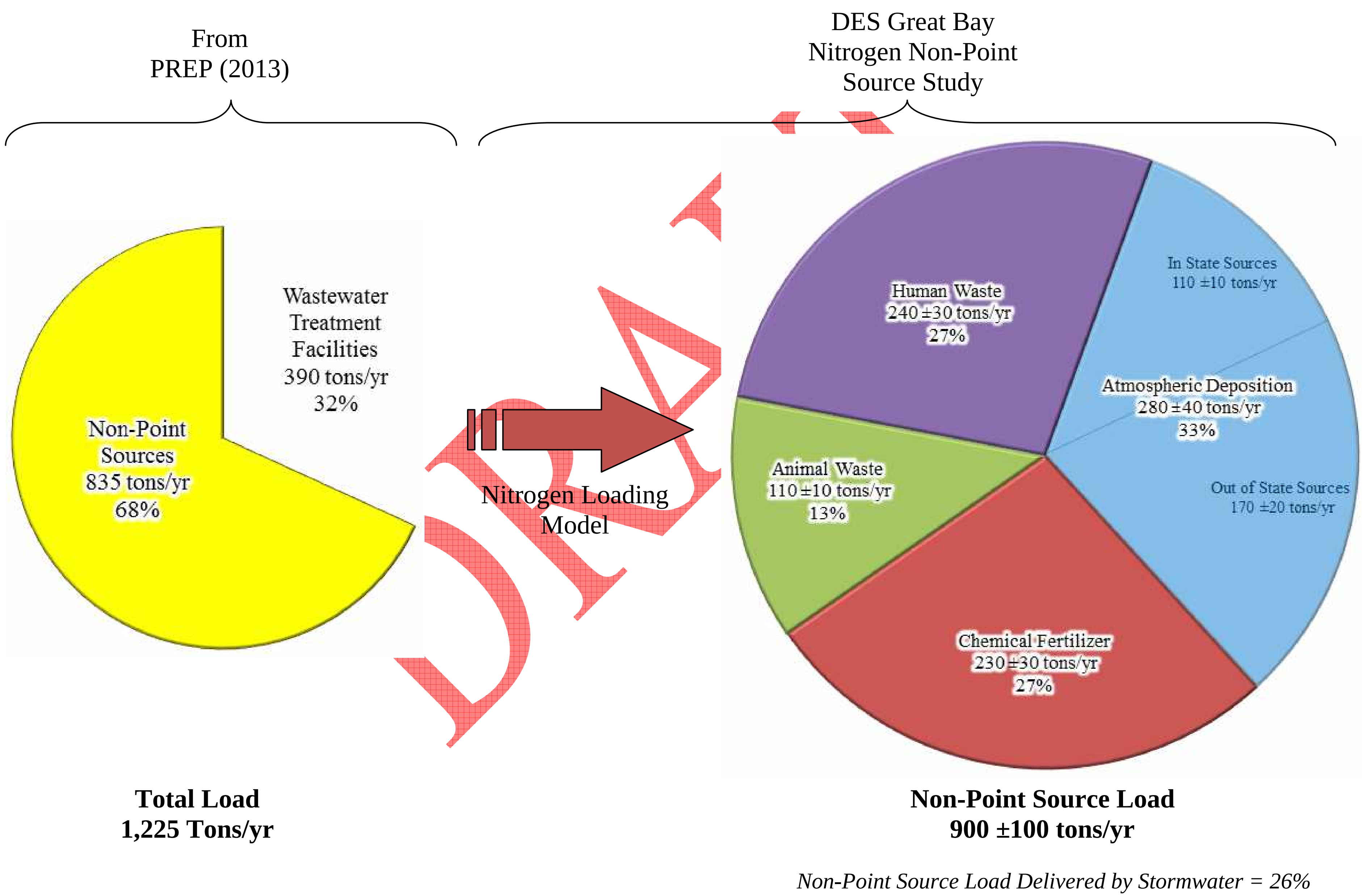
The model used in this study is the Nitrogen Loading Model, as originally published in Valiela et al. (1997). The default Nitrogen Loading Model tracks nitrogen inputs from atmospheric deposition, chemical fertilizers, and human waste discharged through septic systems. These sources are then routed through surface waters and groundwater to the estuary as a delivered load of nitrogen. The model was customized for this study by adding animal waste as an additional source of nitrogen and incorporating a stormwater/surface water transport pathway. Local data on atmospheric deposition rates, septic systems, and recreational fields were developed as inputs to the model. The model output was found to match field measurements of non-point source nitrogen loads from eight watersheds within the relatively small model uncertainty of +/-13%.

For the watershed draining to the Great Bay Estuary, the model predicted a non-point source nitrogen load of 900 tons per year (+/-100 tons/yr). This estimate corresponds well with the most recent field measurement of non-point source load (835 tons/yr) (PREP, 2013). The breakdown of nitrogen non-point sources from the model of delivered loads to the estuary is:

- Atmospheric Deposition – 33% (280 +/-40 tons/yr) – Out-of-state sources account for 62% of this source.
- Human Waste – 27% (240 +/-30 tons/yr) – This load is exclusively from septic systems because loads from wastewater treatment facilities were not considered in this study. (The nitrogen load to the estuary from wastewater treatment facilities was 390 tons/yr in 2009-2011 (PREP, 2013). The combined contribution of nitrogen from human waste is 240 + 390, or 630 tons/yr).
- Chemical Fertilizer – 27% (230 +/-30 tons/yr) – Lawns and agricultural areas each contributed 48% of this load. Recreational fields were responsible for 4%.
- Animal Waste - 13% (110 +/-10 tons/yr) – Livestock accounted for 80% of this load. Only a small fraction of the load was from pet waste.

Nitrogen loads were also modeled for individual subwatersheds and towns in the study area to identify "hot spots" of non-point source pollution. These results may be useful for towns or watershed groups for prioritizing nitrogen reduction efforts or as a starting point for more detailed studies of non-point sources. However, more detailed inventories of non-point sources will be needed to track the effects of nitrogen reduction efforts in smaller areas.

Figure ES: Summary of Non-Point Source Nitrogen Loads to the Great Bay Estuary



I. Introduction

The Great Bay Estuary is 21 square miles of tidal waters located in southeastern New Hampshire. It is one of 28 "estuaries of national significance" established under the Environmental Protection Agency's National Estuary Program. In 2009, most of this estuary was placed on New Hampshire's 303(d) list for impairments associated with total nitrogen (hereafter "nitrogen"). Specifically, low dissolved oxygen, macroalgae blooms, and declining eelgrass habitat have been observed in the estuary (DES, 2012).

Sixty-eight percent of the nitrogen that ends up in the Great Bay Estuary originates from sources spread across the watershed rather than point sources such as municipal wastewater treatment facilities (DES, 2010; PREP, 2013). These sources of nitrogen are called non-point sources and consist of atmospheric deposition, fertilizers, human waste disposed into septic systems, and animal waste. The purpose of this study is to determine how much nitrogen each non-point source type contributes to the estuary. The nitrogen loads from municipal wastewater treatment facilities have been reported elsewhere (DES, 2010; PREP, 2012; PREP, 2013) and, therefore, are not included in this study except to provide context.

II. Methods

a. Study Area

The focus of this study is the watershed draining to the Great Bay Estuary. This watershed is in the Piscataqua Region which covers 1,086 square miles and parts of 61 municipalities in the states of New Hampshire, Maine, and Massachusetts in the northeastern U.S.A. The watershed for the Great Bay Estuary covers most of the Piscataqua Region (1,023 square miles). The remaining area drains to the Hampton-Seabrook Estuary or directly to the Atlantic Ocean.

In this study, the full Piscataqua Region watershed was split into smaller subwatersheds for three purposes. First, the watersheds of the eight major tributaries draining to the Great Bay Estuary were delineated so that measured nitrogen loads from these tributaries could be used to verify the model output. Second, the full watershed was divided into the 40 subwatersheds (the most current HUC12 boundaries, see definitions on page ii) to look for "hot spots" of non-point source nitrogen loading. Third, the study area was divided by the political boundaries of the 61 municipalities in New Hampshire, Maine, and Massachusetts so that town-wide nitrogen loads could be calculated. Overall, the intersections of these three boundaries split the Piscataqua Region into 215 small study areas for modeling purposes (Figure 1).

b. Types of Nitrogen Included in the Study

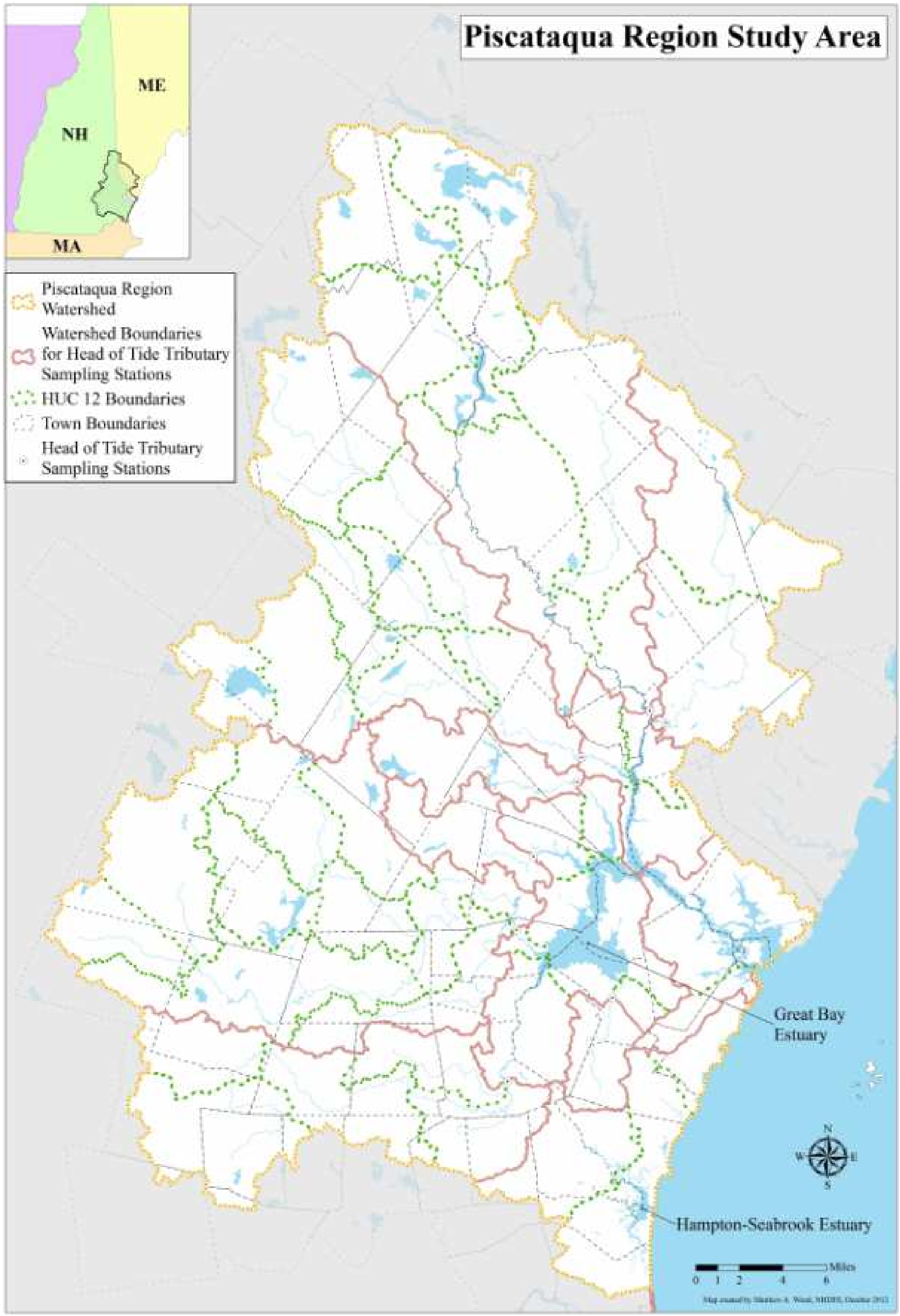
Nitrogen is the most abundant gas in the atmosphere. It is non-reactive in its gaseous form. The only natural processes that convert non-reactive nitrogen to reactive nitrogen are biological nitrogen fixation by specialized microbes associated with plants and, to a lesser extent, high temperature events, such as lightning. As a result, prior to human development, reactive nitrogen was scarce in natural ecosystems, with production of reactive nitrogen balanced by the natural processes that converted reactive nitrogen back to non-reactive nitrogen (Galloway et al., 2003).

For over one hundred years, human activities have vastly increased the production of reactive nitrogen, with the greatest increases occurring since 1960, mirroring the trend of increasing population. Reactive nitrogen production was accelerated by the manufacture of chemical fertilizer, the combustion of fossil fuels, and the cultivation of certain crops that biologically fix nitrogen from the atmosphere. Globally, these human activities have increased the reactive nitrogen production from 33 billion pounds per year in 1860 to 364 billion pounds per year in 2000. The amount of reactive nitrogen created for chemical fertilizers was greater than all the other sources combined (Galloway et al., 2003).

For the Piscataqua Region watershed, this study quantifies the imports and exports of reactive nitrogen created or enhanced by human activities. The specific sources of anthropogenic nitrogen considered are: deposition of nitrogen from the atmosphere (largely from pollution), application of chemical fertilizers, human waste disposed through septic systems, and animal waste. Reactive nitrogen from fossil fuel combustion for power generation or automobiles enters the watershed in the form of air pollution that settles onto the land surface. Reactive nitrogen from chemical fertilizers can be imported to the study area either through fertilizer imports directly (e.g. chemical fertilizers) or through imports of food and feed that were grown elsewhere (e.g. crops imported from outside the watershed). Animal waste contains nitrogen that was imported as animal feed. Nitrogen in imported food is converted to human waste which is either sent to a municipal wastewater treatment facility or an individual septic system. Nitrogen loads to the estuary from wastewater treatment facilities have been quantified in previous reports (DES, 2010; PREP, 2012; PREP, 2013). Therefore, this study will focus on nitrogen loads to the estuary from non-point sources.

Natural sources of nitrogen to the study area are expected to be small compared to the anthropogenic sources. Nitrogen can be fixed from the atmosphere by certain plant-microbe combinations in forests and in row crops such as alfalfa. However, Boyer et al. (2002) and Driscoll et al. (2003) have reported that nitrogen fixation by forests and crops in the Northeast amounts to less than 10% of the imported nitrogen. Fixation by row crops is an agricultural process, not a natural process, because these crops are specifically cultivated by humans and would not exist in large quantities otherwise. Animal waste from wildlife is often thought to be a significant source of nutrients. However, wildlife in the watershed typically eat locally-grown food sources. Animal waste from wildlife is not a new source of nitrogen to the watershed but rather a recycling of nitrogen within the system. Therefore, it is expected that the nitrogen cycle in the study area is dominated by anthropogenic sources. The effects of natural sources of nitrogen on loads to the estuary are expected to be small and variable and accounted for within the uncertainty range (+/-13%) of the model. Comparisons between current and 'background' or 'natural' nitrogen loads were used to verify this assumption.

Figure 1: The Piscataqua Region Divided into the 215 Small Study Areas



c. Nitrogen Loading Model

The model used for this study is the Nitrogen Loading Model (NLM) as originally published in Valiela et al. (1997). The NLM has accurately predicted nitrogen loads in Waquoit Bay, Massachusetts (Valiela et al., 2000), Barnegat Bay, New Jersey (Bowen et al., 2007), and in 74 small embayments in southern New England (Latimer and Charpentier, 2010). The model output is an annual average nitrogen load. The model does not predict how non-point source nitrogen loads may change over the course of a year or during a particular weather event.

Inputs of Non-Point Source Nitrogen

The default NLM tracks nitrogen inputs from human activities from three major sources: (1) atmospheric deposition; (2) chemical fertilizers; and (3) human waste. For this study, animal waste has been added to the model as another source of nitrogen. Valiela et al. (1997) considered this factor originally but decided that it would be negligible in the small Waquoit Bay watershed. However, for the larger Piscataqua Region watershed animal waste may be important. Figure 2 and Figure 3 are simplified and detailed outlines of the model used for this study, respectively.

Atmospheric deposition rates for the model were taken from measurements in the study area in 2009. In addition, the DES Air Resources Division used a regional dispersion model to estimate how much of the nitrogen in atmospheric deposition comes from sources outside of New Hampshire and from different source categories (e.g., mobile sources, power generation, etc.). Appendix A contains a summary of the methods used for the air dispersion modeling and an analysis of how the deposition rate is expected to change over the next 10 years.

The model handles nitrogen from atmospheric deposition differently depending on the type of land use on which it falls. Land use data covering the entire study area was obtained from the NOAA Coastal Change Analysis Program 2006 data layer (Landsat TM, 30-meter resolution[1]). Impervious surface data for the study area in 2010 was obtained from the University of New Hampshire (Landsat TM, 30-meter resolution[2]). While more detailed land use and impervious cover datasets are available for some parts of the study area, only ones that covered the entire area were used. These datasets were used to estimate Connected Impervious Area and Disconnected Impervious Area in each study area following the approach from Sutherland (1995)[3]. The area of natural vegetation and surface waters in each study area were also estimated from these datasets.

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[1] http://www.csc.noaa.gov/crs/lca/northeast.html
[2] http://www.granit.unh.edu/data/datacat/pages/coastalimperv10.pdf
[3] The Nitrogen Loading Model tracks nitrogen loads from two different types of impervious surfaces: (1) roofs and driveways and (2) roads, runways, and commercial areas. Runoff from roofs and driveways is presumed to flow "onto adjoining turf, where there are losses of nitrogen." Runoff from roads, runways, and commercial areas "largely flows into gutters and drains, and accumulates in catch basins". (Valiela et al., 1997) These two types of impervious surfaces fit the current definitions of "disconnected impervious area" (DIA) and "connected impervious area" (CIA).

Appendix B provides detail on the methods used for land use calculations. Agricultural lands, managed turf areas, and lawn area were estimated separately and are discussed below.

The area of different agricultural crops in the study area was estimated from the USDA National Agricultural Statistics Service Cropland Data Layer for 2011 (Landsat TM, 30-meter resolution[4]). The expected fertilizer application rates for different crops were obtained from the USDA National Agricultural Statistics Service using data for New York as a surrogate for New Hampshire. New York was the closest state to the study area for which data were reported. Agricultural experts at UNH Cooperative Extension were also consulted regarding fertilizer applications rates, particularly for hay and pasture fields. Details of the methods used to estimate agricultural lands and fertilizer application rates are provided in Appendix C.

Golf courses, ball fields, and parks all have large areas of managed turf. The total area of managed turf in the study areas was determined by identifying all of these fields and delineating their boundaries using computer mapping software and aerial imagery from 2010-2011[5] with 1-foot or 1-meter resolution. Golf courses and ball fields, relatively large features, were easily identified using the imagery. The fertilizer application rate for each field was obtained through a survey of the persons responsible for managing the fields. The survey had a 48% response rate. Average fertilization rates from the survey responses were used for the fields for which the survey was not completed. Details of the process used to delineate the boundaries of the managed turf areas and the survey are provided in Appendix D.

The area of lawns in the study area was estimated by quantifying lawn coverage in randomly selected areas and extrapolating the results to the rest of the watershed. In 80 randomly selected areas with homogeneous land use, the total coverage of lawn was digitized using aerial imagery (as described above). These data was used to estimate the average percent of each developed land use class that was covered by residential lawns. The total area of lawns was estimated by multiplying these percentages by the area covered by each land use class. Fertilizer application rates for lawns and the percent of lawns that are fertilized in any given year were taken from the literature. Appendix E contains details of the methods used to estimate lawn area and fertilization rates.

Animal waste was estimated by creating an inventory of priority livestock and pets and using the per animal nitrogen excretion rates from Boyer et al. (2002). Cows, horses, dogs, and cats were identified as priority animals based on the animal totals for the four counties in the study area from the 2007 USDA Census of Agriculture. These four species accounted for 96% of the nitrogen in animal waste. The number of these animals in each town in the study area was obtained from the State Department of Agriculture, State Veterinarian, individual farms, town clerks, and formulas from the American

[4] http://www.nass.usda.gov/research/Cropland/metadata/metadata_nh11.htm
[5] Imagery for New Hampshire and Massachusetts areas http://www.granit.unh.edu/resourcelibrary/specialtopics/2010aerialphotography/index.html. Imagery for Maine areas, http://geolibportal.usm.maine.edu/geonetwork/srv/en/metadata.show?id=926.

Veterinary Medical Association. Watershed inputs from pet waste were estimated after taking into account expected rates of pet waste pick-up by owners reported in the literature. Details of the methods for estimated animal waste inputs are provided in Appendix F.

Human waste inputs through septic systems were estimated by determining the percent of the population in each census block that was not served by municipal sewer networks. The remaining population was assumed to use septic systems for waste disposal. The sewered population was determined based on previous work by the USGS Water Demand Model for New Hampshire (Hayes and Horn, 2009), maps of sewer lines, and consultation with public works officials. The number of people residing in each census block was obtained from the 2010 U.S. Census. Each person was assumed to excrete 10.6 pounds of nitrogen per year (Valiela et al., 1997). Appendix G contains the details of methods used to determine the number of people who use septic systems for waste disposal in the study area.

All of the input datasets were collected between 2005 and 2012, with most between 2010 and 2012. The atmospheric deposition rates are specific to 2009, a year which experienced rainfall and hydrologic conditions that were typical for New England and, therefore, consistent with the model assumptions. Consequently, the modeled time period for this study most closely represents conditions in 2009.

Transport Pathways

Within the Nitrogen Loading Model, the nitrogen imported from the sources described above is applied to different types of land use (or the subsurface through septic systems) and transported to the estuary through a groundwater pathway. A large fraction of the nitrogen that enters the watershed from these sources is permanently removed by denitrification to nitrogen gas. The remainder of the imported nitrogen is delivered from the watershed to the estuary. See Appendix H for details of the delivery factors for the groundwater transport pathways.

In the Great Bay Estuary watershed much of the nitrogen will follow the groundwater pathways per the default NLM. However, the soils in the Great Bay Watershed are not as sandy as those on Cape Cod. Some of the nitrogen applied to the land surface will be carried directly into surface waters by stormwater runoff. Therefore, a stormwater/surface water transport pathway was added to customize the NLM for conditions in the Great Bay Estuary. The components of this pathway are:

- Connected Impervious Area: Connected Impervious Area generates stormwater runoff that is carried directly into the stormwater drainage system and then discharged directly to surface waters. One hundred percent of the nitrogen applied to these areas was assumed to travel through the stormwater/surface water pathway.
- Lawn Area, Managed Turf, Agriculture, and Disconnected Impervious Area: Most of the nitrogen applied to these land uses will be transported by the default groundwater pathway. However, some fraction of the nitrogen is expected to be

transported to surface waters by stormwater runoff when the infiltration capacity of the soils is exceeded. After a review of the scientific literature and model validation using measured loads, the fraction assumed for the model was 12% (see details in Appendix H).

- Lake, River, and Estuary Areas: Nitrogen falling from the atmosphere directly onto surface waters does not pass through the groundwater pathway. One hundred percent of the atmospheric deposition onto surface waters was assumed to travel through the surface water pathway.
- Delivery Factor: Some of the nitrogen in the surface water pathway will be lost during transport. The Estuarine Loading Model (ELM), a companion model to the NLM from Valiela et al. (2004), was used to estimate these losses. Essentially, the ELM assumes the mean percent loss of nitrogen in freshwater streams is 13%. The delivery factors for the surface water pathway are described in Appendix H.

In addition to the pure groundwater and stormwater/surface water pathways, nitrogen is likely transported through a mixture of these two pathways. Some nitrogen may initially enter the groundwater and then discharge to a river or lake before reaching the estuary. This combination pathway was too complicated to model. However, the *effects* of this pathway are likely accounted for by the stormwater/surface water pathway.

Results Summary

Summary tables, figures, and discussion of the results for the watershed draining to the Great Bay Estuary as a whole are provided in Section III of this report.

The model was also run for subwatersheds and towns in the Piscataqua Region to provide local information to decision-makers. These results are provided in the form of figures and tables in Section V of this report.

The authors of the model determined the variability of the model based on its input parameters to be 38% for individual applications and 13% on average[6]. For this study, the NLM was run on multiple different study areas with the results summed, so the average variability is the relevant target value. For summary graphics, the results were expressed with error bars and were rounded to the same decimal place as the error bars. No rounding was performed on tables and figures other than the summary graphics in order to accommodate review without introducing round-off errors. However, all model results should be recognized to have an inherent uncertainty of +/-13%. Detailed methods for this study are provided in appendices as shown in Table 1.

[6] Average of the two estimates of variability from Table 11 of Valiela et al. (1997).

Table 1: List of Appendices Containing Detailed Methodologies for Nitrogen Import and Cycling

Source	Land Use or Process	Detailed Methods
Atmospheric Deposition	Deposition on different land use types	Appendix A (deposition rate) Appendix B through E (land use)
Chemical Fertilizer	Agricultural Lands	Appendix C
	Recreational Fields	Appendix D
	Lawns	Appendix E
Animal Waste	Manure on agricultural lands	Appendix F
	Pet waste on different land use types	Appendix F
Human Waste	Septic systems	Appendix G
Delivery Factors	Transport pathways	Appendix H

Figure 2: Simplified Diagram of the Nitrogen Loading Model for the Great Bay Nitrogen Non-Point Source Study

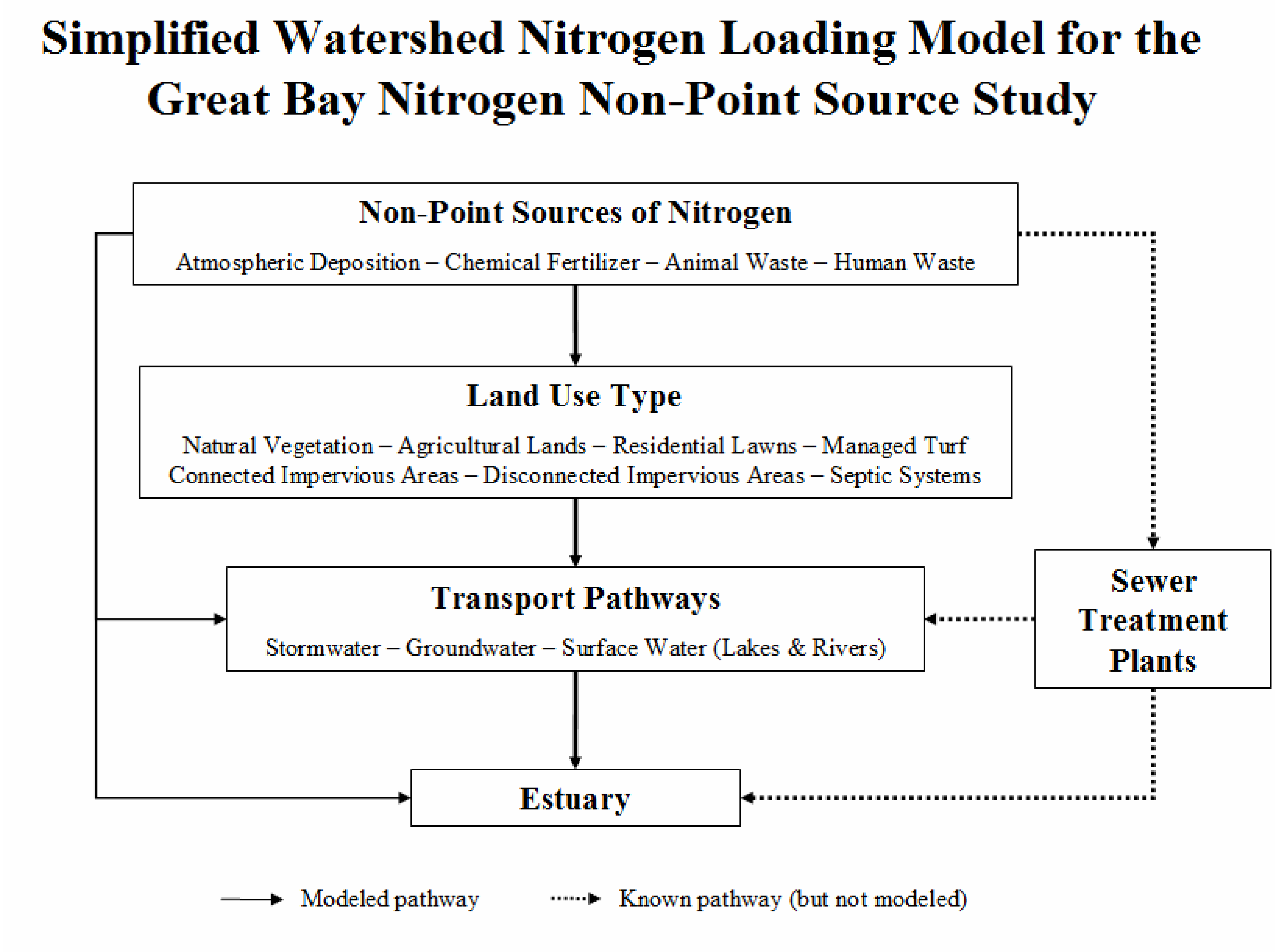
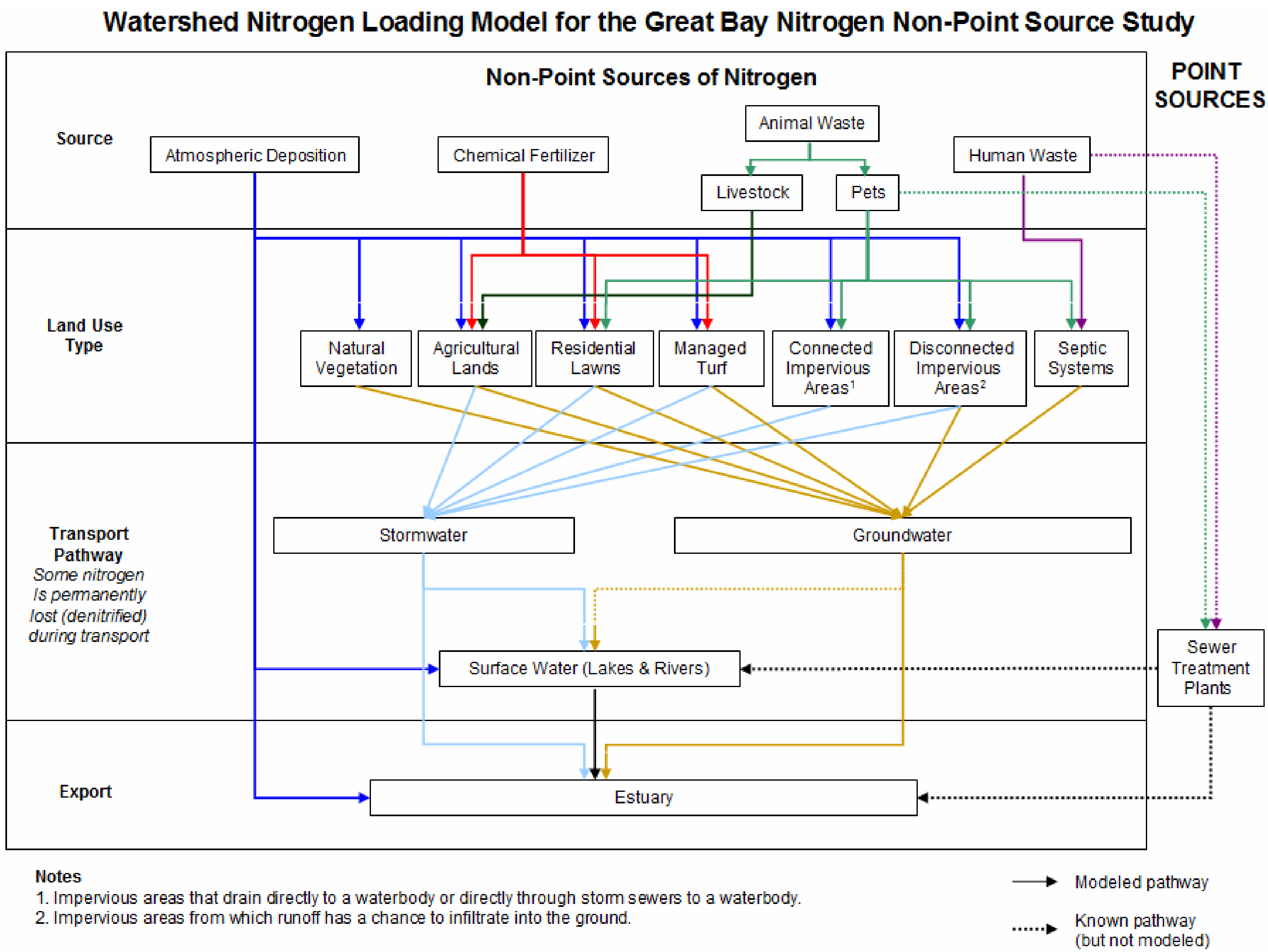


Figure 3: Detailed Diagram of the Nitrogen Loading Model for the Great Bay Nitrogen Non-Point Source Study



d. Model Validation

Input parameters for the model were researched in depth to obtain the best-available, local information to represent conditions in the Piscataqua Region. The chosen values were validated by comparisons to other studies to ensure accuracy.

The model output was validated using measurements of nitrogen loads from the eight major tributaries to the Great Bay Estuary. PREP (2012) used the most recent monthly data on nitrogen concentrations at the head-of-tide to calculate the total nitrogen load from non-point sources in each of the eight major watersheds. The NLM was run for these same watersheds. The model predictions were then compared to the measured loads to determine the accuracy of the model.

e. Quality Assurance

The model results were vetted by both internal and external review. An internal review was conducted by DES technical staff to verify the calculations and methods. An external review was completed by Dr. Ivan Valiela of the Marine Biological Laboratory at Woods Hole, MA.

f. Public Participation

DES developed two customized, geospatial datasets for this study. The first was a datalayer showing the percent of the population in each census block that uses a septic system for waste disposal. DES contacted each of the municipalities in the study area in August 2011 with a draft of this datalayer. DES accepted comments from the municipalities and revised the datalayer accordingly (Appendix G). The second datalayer showed the boundaries of every ball field, golf course, public parks, or other type of managed, recreation turf in the watershed. In October 2011, DES mailed maps of the managed turf boundaries to the organization responsible for maintaining them (e.g., municipalities, school districts, golf courses, etc.). DES accepted comments and revised the boundaries accordingly. DES also compiled results of a survey from the turf managers regarding turf fertilization practices (Appendix D).

The final report was released for public comment from May 16, 2013 through June 17, 2013. Comments received by the due date have been summarized and responded to in Appendix I. [Note: Not yet completed]

III. Results & Discussion

a. Validation of Model Input Parameters

The accuracy of any model depends on having correct input data. Each of the model input variables for the NLM was researched in depth to obtain the best available and local information to represent conditions in the Piscataqua Region. The chosen values were validated by comparisons to other studies to ensure accuracy.

The atmospheric deposition rate for 2009 was determined to be 5.21 lb/ac/yr based on measurements at a site near the center of the watershed in 2009 (Thompson Farm in Durham, NH). The chosen value was lower than the previous estimate of 6.24 lb/ac/yr in 2009 from Daley et al. (2010) because it takes into account the increasing trend in the wet-to-dry deposition ratio. The chosen value was confirmed by a regional deposition trending analysis that predicted a deposition rate of 5.79 lb/ac/yr based on emissions data for 2009. In addition, a regional air dispersion model was used to show that 62% of the all nitrogen deposition in the Piscataqua Region was from sources outside of New Hampshire, 53% was from mobile sources, and 27% was from power generation. The atmospheric deposition rate of nitrogen is expected to decline by one-third by 2020 as a result of USEPA rules and programs requiring emission reductions.

Impervious surfaces were found to cover 10% of the land area of the Piscataqua Region. By using the approach from Sutherland (1995), it was estimated that approximately one third of the impervious surfaces were Connected Impervious Area which discharged stormwater runoff directly to surface waters. PREP (2013) reported that 9.6% of the Piscataqua Region watershed was covered by impervious surfaces, which matches the estimate in this report.

Agricultural lands covered 39,226 acres or 6% of the land area in the Piscataqua Region. The largest crop was hay (88% of the agricultural area) followed by alfalfa (5%), and corn (4%). Fertilizer application rates ranged from 63 lb N/ac for corn to 0 lb N/ac for alfalfa, which is a nitrogen fixing crop. Ruddy et al. (2006) reported county-level estimates of farm fertilizer use for the United States. On a per acre basis, the nitrogen application rates in 1998 reported by Ruddy et al. (2006) were 21-33 lb N/ac for Strafford and Rockingham counties. For comparison, the estimated farm fertilizer rates in 2011 from this study were 25-26 lb N/ac. Therefore, the application rates for this study were within the range of reported rates for 1998 by Ruddy et al. (2006).

Recreational fields with managed turf covered 2,526 acres in the Piscataqua Region. There were 22 golf courses, 102 school athletic fields, and 103 town parks or fields. Fertilizer application rates were obtained through a manager survey for 48% of the fields. The results showed that the average yearly fertilizer application rate of nitrogen was 2.25 lb N/1000 ft^2 for golf courses, 1.89 lb N/1000 ft^2 for school fields, and 1.24 lb N/1000 ft^2 for town fields. The application rates are reported in the units typically used by landscaping companies (pounds of nitrogen per 1,000 square feet or lb N/1000 ft^2).

These average yearly application rates are consistent with other published values and/or recommendations. For example, Latimer and Charpentier (2010) used a value of 2.36 lb N/1000 ft^2 for recreational fields for a study of nitrogen loads to estuaries in southern New England. The survey also found that the fertilized area of golf courses (fairways, greens, tees) typically amounted to 42% of the total golf course size, and that 87% and 61% of school and town fields, respectively, were fertilized in a given year. These percentages were used to prorate the fertilizer application rates for the model.

Residential lawns were estimated to cover 19,077 acres in the Piscataqua Region (2.7% of the watershed), which is an order of magnitude more than managed turf and more than any other 'crop' besides hay. This finding matches previous work by Milesi et al. (2005) at the national level. The average lawn area in the Piscataqua Region ranged from 0.05 acres/home for high density development areas to 0.30 acres/home for open space areas. This range of values appears to be credible because it brackets the value of 0.12 acres/home published by Latimer and Charpentier (2010). Based on a review of the literature, fertilizer use was estimated to occur on 64% of lawns in any given year at a rate of 2 lb N/1000 ft^2. For validation, the estimates of nitrogen fertilizer use on residential lawns and managed turf were compared against the non-farm fertilizer use reported for Strafford and Rockingham counties in Ruddy et al. (2006). The predicted fertilizer use in 2006 matched the values from Ruddy within 7% for both counties.

In the 2007-2012 time period, there were approximately 2,468 horses, 2,572 cows (mostly dairy), 51,568 licensed dogs, and 94,037 cats in the Piscataqua Region watershed. These values are likely low estimates because they are largely based on surveys of commercial farms[7] for horses and cows and official dog registrations with town clerks. Some of the feed and grass that is eaten by animals is grown in the watershed using either chemical fertilizer or atmospheric deposition as the source of nutrients. Animal waste from locally grown feed or pasture represents a recycling of these nutrients, not a new source. Therefore, there is the potential for the animal waste component of the model to double count some of the nitrogen already tracked as fertilizer and atmospheric deposition. However, any double counting that may exist in this approach is expected to be small relative to larger sources (human waste, chemical fertilizer, atmospheric deposition) and will be partially offset by low estimates of the total livestock in the watershed.

Slightly more than half of the people in the Piscataqua Region watershed used septic systems for waste disposal. The study showed that 177,548 of the 325,775 people (55%) in the watershed lived outside municipal sewer service areas. Maps of sewered areas from this study were checked by municipal officials for quality assurance (see Appendix G).

[7] The USDA Agricultural Census covers "any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold, during the census year." Residential animals are not included.

b. Validation of Model Output

The output of the NLM was validated using measurements of nitrogen loads from the eight major tributaries to the Great Bay Estuary (Figure 4 and Table 2). For watersheds with upstream wastewater treatment facilities, the load from the facilities was subtracted from the total load in order to isolate the non-point source load to compare to the non-point source model results. The graph on the left of Figure 4 compares the measured and modeled loads in units of pound per year. The graph on the right shows the same data but normalized by watershed size and expressed as yields (lb/ac/yr). The uncertainty in each of the points is shown by error bars. Both graphs indicate good correspondence between the model results and actual measurements. The standard error of the regressions was 11-12% of the mid-point of the datasets.

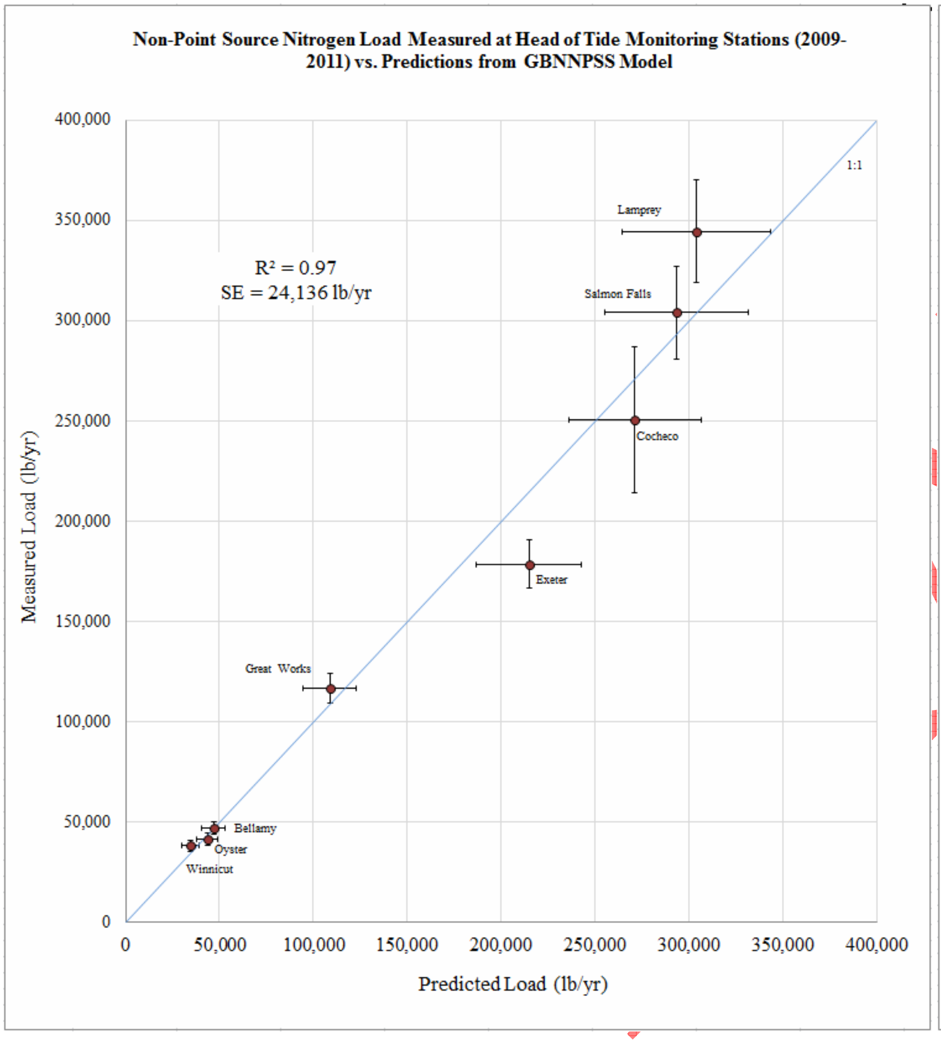
Accuracy and simplicity are often competing objectives for modeling studies. Models can always be made more accurate through customization but then they are more difficult to explain and less transparent. Ultimately, models should be as simple as possible to achieve the objectives of the study. In order to improve the fit of the model, customized nitrogen attenuation factors for each watershed would be required. This change would add significant complexity without corresponding benefit relative to the overall objectives of the study. Therefore, it was decided not to customize the model any further. The model provides reasonably accurate predictions of the non-point source loads from Great Bay watersheds within the expected accuracy of 13%. However, the model may lose accuracy at smaller scales unless more detailed input datasets are used.

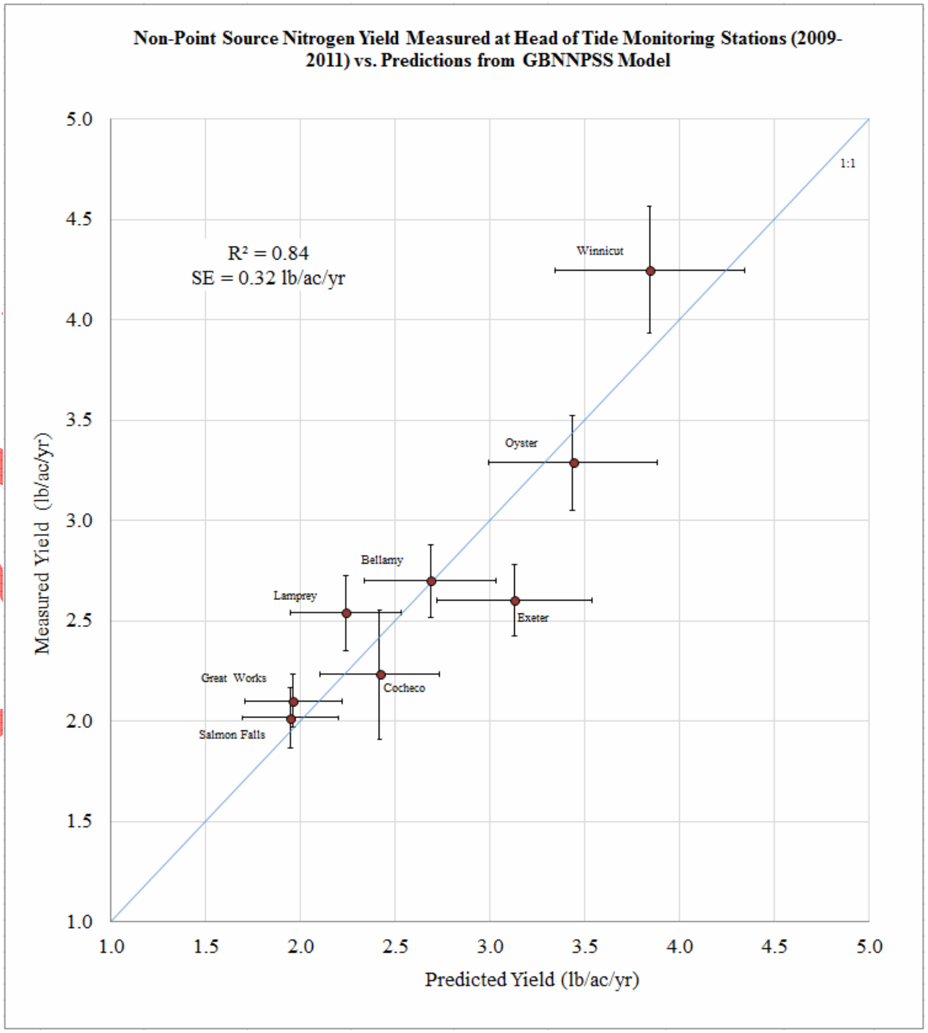
Table 2: WWTF and Non-Point Source Nitrogen from Great Bay Watersheds 2009-2011 (from PREP, 2012)

Watershed	TN Load[1] (lb/yr)	Upstream WWTF TN Load[2] (lb/yr)	Non-Point Source TN Load (lb/yr)	Modeled Non-Point Source Load (lb/yr)
Winnicut River	38,280	0	38,280	47,319
Exeter River	178,620	0	178,620	265,452
Lamprey River	352,600	8,240	344,340	309,225
Oyster River	41,760	0	41,760	71,954
Bellamy River	47,080	0	47,080	67,620
Cocheco River	538,020	287,540	250,480	303,187
Salmon Falls River	344,560	40,620	303,940	312,562
Great Works River	119,720	3,080	116,620	108,948

1. TN loads estimated using USGS software "LOADEST" with water quality data from the PREP Tidal Tributary Monitoring Program and streamflow data from USGS.
2. The following wastewater treatment facilities (WWTFs) are located upstream of the tributary monitoring stations. The Epping WWTF is upstream of the Lamprey River station. The Rochester and Farmington WWTFs are upstream of the Cocheco River station. The Milton, Berwick, Somersworth and Rollinsford WWTFs are upstream of the Salmon Falls River station. The North Berwick WWTF is upstream of the Great Works River station. Upstream WWTF loads were reduced using an attenuation loss model to estimate the delivered load to the estuary.

Figure 4: Model Output Validation - Measured Watershed Loads and Yields vs. Model Predictions





c. Model Output for the Great Bay Estuary Watershed

For the watershed draining to the Great Bay Estuary, the NLM predicts a non-point source nitrogen load of 900 tons per year (+/-100 tons/yr) (Figure 5). This estimate corresponds well with the most recent field measurement of the non-point source load (835 tons/yr) (PREP, 2013). The breakdown of nitrogen non-point sources from the model of delivered loads to the estuary is:

- Atmospheric Deposition – 33% (280 +/-40 tons/yr) – Out-of-state sources account for 62% of this source.
- Human Waste – 27% (240 +/-30 tons/yr) – This load is exclusively from septic systems because loads from wastewater treatment facilities were not considered in this study. (The nitrogen load to the estuary from wastewater treatment facilities was 390 tons/yr in 2009-2011 (PREP, 2013). The combined contribution of nitrogen from human waste is 240 + 390, or 630 tons/yr.)
- Chemical Fertilizer – 27% (230 +/-30 tons/yr) – Lawns and agricultural areas each contributed 48% of this load. Recreational fields were responsible for 4%.
- Animal Waste - 13% (110 +/-10 tons/yr) – Livestock accounted for 80% of this load. Only a small fraction of the load was from pet waste.

Overall, 78% of the nitrogen added to the watershed is lost before it reaches the estuary (Figure 6). The model predicts that 862 of the 3,978 tons of nitrogen applied to the land surface or discharged to a septic system were delivered to the estuary. Measurements of nitrogen inputs and outputs for watersheds in the study area have shown similar levels of nitrogen retention. Daley et al. (2010) reported that sub-basins of the Lamprey River watershed typically had nitrogen retention rates of 72 to 91%. The largest retention rates in the model are for natural vegetation and forests (91%). The smallest retention rates are for runoff from connected impervious surfaces (13%). Therefore, nitrogen retention in a watershed generally decreases as development increases.

The model predicts that stormwater delivers 26% of the non-point source nitrogen to the estuary (Figure 7). Stormwater is a transport pathway for nitrogen applied to lawns, agricultural lands, and urban lands. Urban stormwater runoff, runoff from agricultural lands, and runoff from lawns each account for approximately one-third of the nitrogen in stormwater.

As a way to identify potential "hot spot" areas, the yield of non-point source nitrogen from each small HUC12 watershed was calculated. The yield is the number of pounds of non-point source nitrogen delivered from the subwatershed to the estuary divided by the area of the subwatershed. A map of the watershed draining to the Great Bay Estuary is shown in Figure 8. The yield of non-point source nitrogen from each subwatershed is color coded on the map. For the entire Piscataqua Region study area, the top twenty percent of subwatersheds had delivered non-point source yields between 3.6 and 4.8 lb/ac/yr. In the Great Bay Estuary watershed, there were 8 HUC12 subwatersheds with yields in this highest category.

- Lower Cocheco River (HUC# 010600030608)

- Great Brook-Exeter River (HUC# 010600030805)
- Squamscott River (HUC# 010600030806)
- Winnicut River (HUC# 010600030901)
- Oyster River (HUC# 010600030902)
- Great Bay (HUC# 010600030904)
- Portsmouth Harbor (HUC# 010600031001)
- Berrys Brook-Rye Harbor (HUC# 010600031002)

The NLM was used to estimate delivered non-point source nitrogen loads from each of the eight major watersheds draining to the Great Bay Estuary, each of the 40 subwatersheds in the region, and each of the 61 towns in the region. In general, the patterns of nitrogen in non-point sources were similar across the different watersheds. Figure 9 and Figure 10 show comparisons between the major watersheds and the whole Great Bay Estuary. Atmospheric deposition, chemical fertilizers, and human waste were the major sources in all the watersheds. The non-point source nitrogen yield for the major watersheds ranged from approximately 2 to 4.2 lb/ac/yr, which brackets the average non-point source yield of 2.6 lb/ac/yr. The percent of the non-point source load delivered by stormwater was within a narrow range of 22 to 34% for the major watersheds. Detailed tables and figures showing the NLM output results for each of the subwatersheds and towns in the Piscataqua Region are provided in Section V of this report. These results may be useful for towns or watershed groups for prioritizing nitrogen reduction efforts or as a starting point for more detailed studies of non-point sources.

The nitrogen yield from temperate zone ecosystems in North America prior to human disturbance has been estimated to be 0.7-1 lb/ac/yr (NRC, 2000 at 122, Howarth, 2008). For the Great Bay Estuary watershed, this ‘pre-development’ nitrogen load would amount to 227 to 315 tons/yr. In contrast, the total nitrogen load from the watershed from both non-point sources and wastewater treatment facilities was 1,225 tons/yr in 2009-2011 (PREP, 2013). Therefore, nitrogen loads to the Great Bay Estuary are currently 4 to 5 times above pre-development levels. Another comparison can be made with the nitrogen loads from the Hubbard Brook Experimental Forest in North Woodstock, NH. Nitrogen yields of 1.2 lb/ac/yr from this forest (Bernal et al., 2012) reflect current atmospheric deposition rates but not human development on the ground because the watershed is pristine. For the Great Bay Estuary watershed, a yield of 1.2 lb/ac/yr would amount to nitrogen load of 408 tons/yr. Current loads are 3 times higher. These estimates of ‘background’ or ‘natural’ nitrogen loads are approximate. The exact amount of nitrogen currently delivered to the estuary from natural processes is unknown given that the nitrogen cycle in the Piscataqua Region is now dominated by human sources. However, these comparisons provide useful reference points for understanding current nitrogen loads compared to what they might have been in the past or with no development in the watershed.

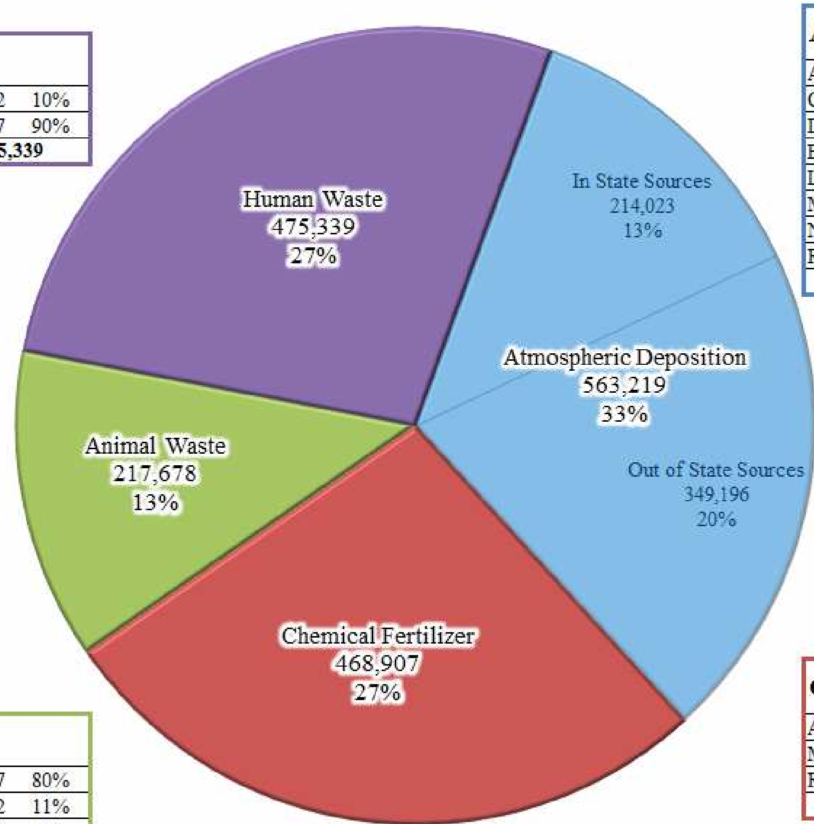
In summary, the NLM output for the watershed draining to the Great Bay Estuary summarized in Figure 5 through Figure 8 provides useful information on the non-point sources of nitrogen to the estuary. It is now clear that human waste from both septic systems and wastewater treatment facilities accounts for 51% of the total nitrogen load to the estuary. The second biggest source, atmospheric deposition, is largely due to out-of-state sources but is declining due to improved emissions controls. Chemical fertilizer is the third biggest source. Fertilizer use on recreational fields and golf courses is a small contributor compared to use on lawns and agricultural lands. Animal waste is the smallest source. The predicted load from animal waste is within the error of the model, especially for pet waste. Finally, the non-point source nitrogen yield was not constant across the whole watershed. Lands closer to the estuary contributed more nitrogen per unit area than lands farther away because of the larger populations and denser development.

Figure 5: Outputs of Non-Point Source Nitrogen by Source Type and Land Use Type for the Great Bay Estuary Watershed

Non-Point Source Nitrogen Delivered to Estuary
Total Load by Source Type and Land Use Type for the Great Bay Estuary Watershed

Human Waste - TN (lb/yr)

Septic within 200m of Waterways*	48,362	10%
Septic >200m from Waterways*	426,977	90%
Total =	**475,339**	



Atmospheric Deposition - TN (lb/yr)

Agriculture	37,041	7%
Connected Impervious Area	85,291	15%
Disconnected Impervious Area	37,371	7%
Estuaries	65,255	12%
Lakes & Rivers	82,844	15%
Managed Turf	2,098	0.4%
Natural Vegetation	236,885	42%
Residential Lawns	16,434	3%
Total =	**563,219**	

Chemical Fertilizer - TN (lb/yr)

Agriculture	225,394	48%
Managed Turf	20,338	4%
Residential Lawns	223,175	48%
Total =	**468,907**	

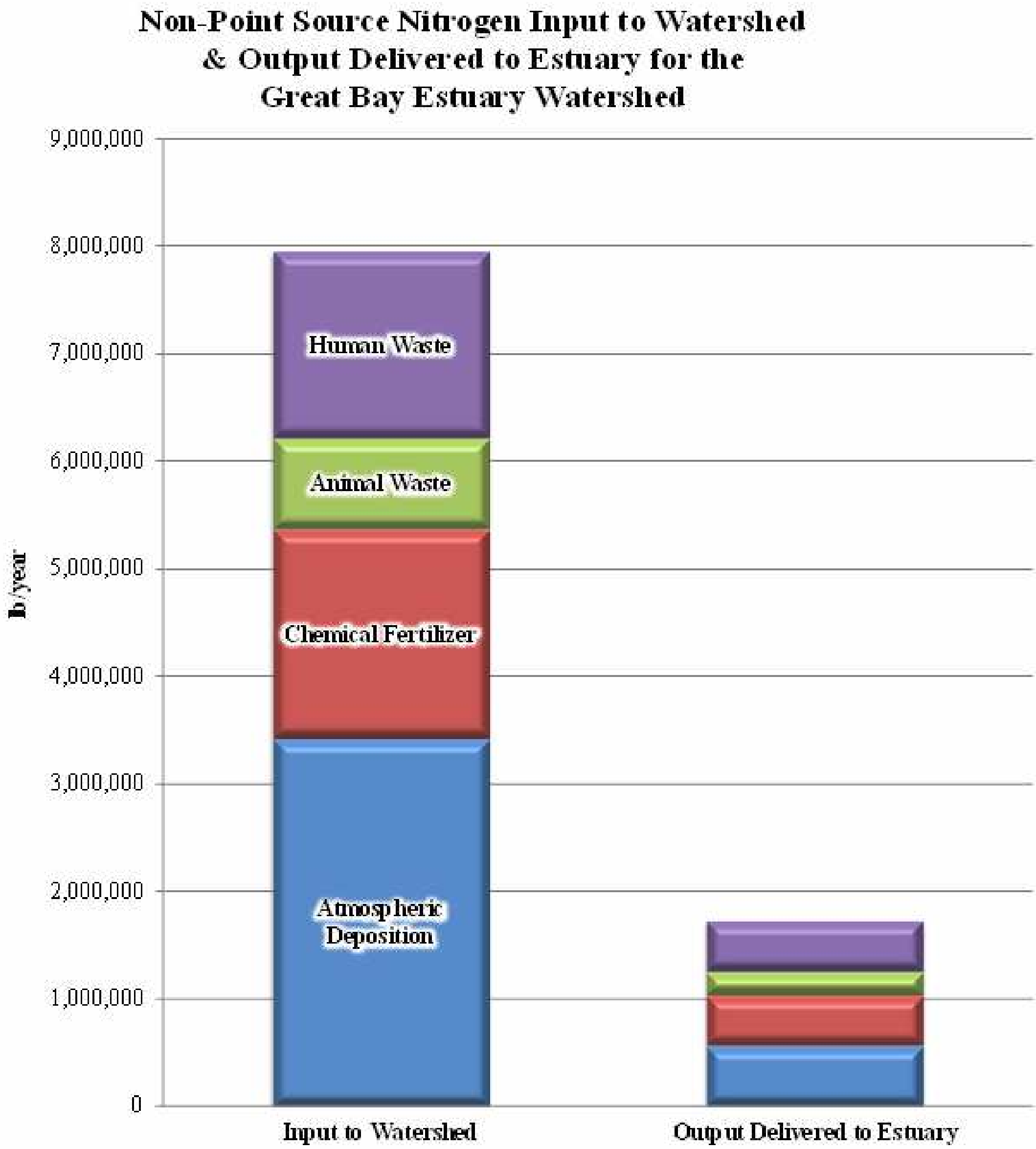
Animal Waste - TN (lb/yr)

Agriculture	173,667	80%
Connected Impervious Area	23,122	11%
Disconnected Impervious Area	11,544	5%
Residential Lawns	5,841	3%
Septic within 200m of Waterways*	332	0.2%
Septic >200m from Waterways*	3,172	1%
Total =	**217,678**	

Total Nitrogen Delivered = 1,725,144 lb/yr

*Waterways include estuaries and 5th order or larger streams

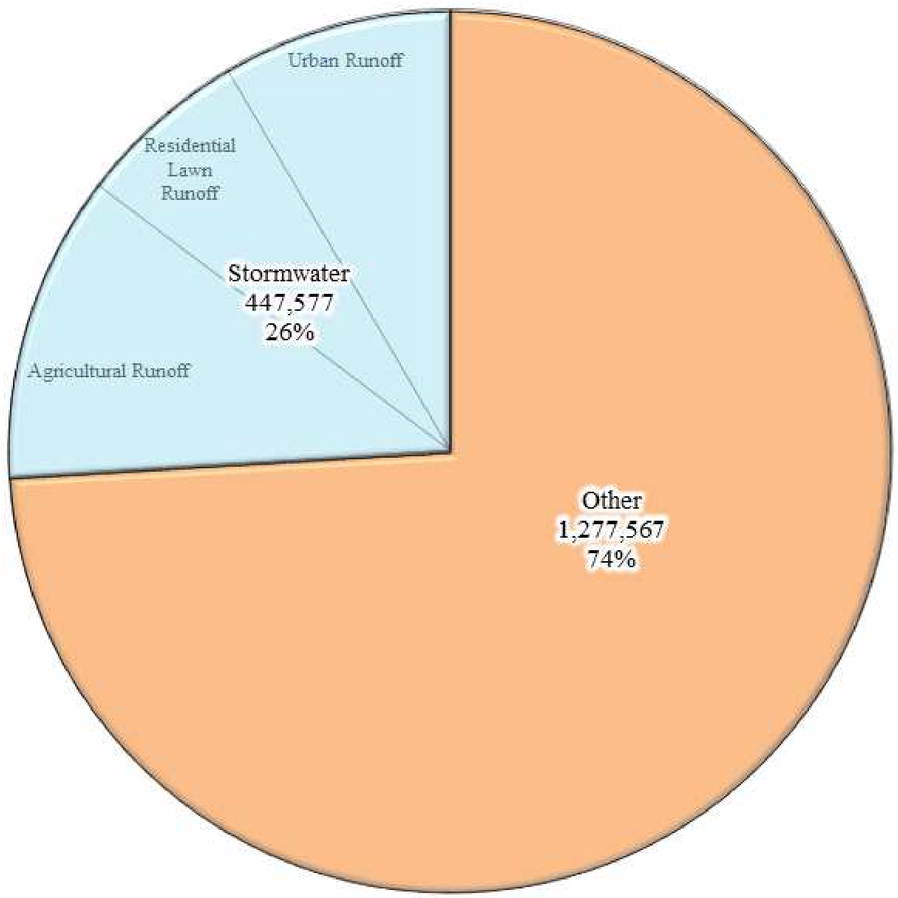
Figure 6: Inputs and Outputs of Non-Point Source Nitrogen by Source Type for the Great Bay Estuary Watershed



Source	Input to Watershed TN (lb/yr)		Output Delivered to Estuary TN (lb/yr)		TN Lost During Transport
Human Waste	1,739,412	22%	475,339	28%	*73%*
Animal Waste	846,937	11%	217,678	13%	*74%*
Chemical Fertilizer	1,949,891	25%	468,907	27%	*76%*
Atmospheric Deposition	3,419,717	43%	563,219	33%	*84%*
Total =	**7,955,957**		**1,725,144**		**78%**

Figure 7: Outputs of Non-Point Source Nitrogen Delivered Through Stormwater for the Great Bay Estuary Watershed

Non-Point Source Nitrogen Delivered to Estuary
Total Load through Stormwater for the Great Bay Estuary Watershed



Stormwater Delivered Load - TN (lb/yr)			
Agricultural Runoff - 43% of Stormwater - 11% of all Pathways			
Agriculture	Animal Waste	75,395	39%
	Atmospheric Deposition	20,442	11%
	Chemical Fertilizer	97,851	51%
	Sub-Total =	**193,688**	
Residential Lawn Runoff - 24% of Stormwater - 6% of all Pathways			
Residential Lawns	Animal Waste	2,536	2%
	Atmospheric Deposition	9,070	8%
	Chemical Fertilizer	96,888	89%
	Sub-Total =	**108,493**	
Urban Runoff - 32% of Stormwater - 8% of all Pathways			
Connected Impervious Area	Animal Waste	23,122	16%
	Atmospheric Deposition	85,291	59%
Disconnected Impervious Area	Animal Waste	6,371	4%
	Atmospheric Deposition	20,624	14%
Managed Turf	Atmospheric Deposition	1,158	1%
	Chemical Fertilizer	8,830	6%
	Sub-Total =	**145,396**	
	Stormwater Total =	**447,577**	
	Total of all Pathways =	**1,725,144**	

Total Nitrogen Delivered = 1,725,144 lb/yr

Figure 8: Non-Point Source Nitrogen Yield (pounds delivered per acre per year) for HUC12 Subwatersheds Draining to the Great Bay Estuary

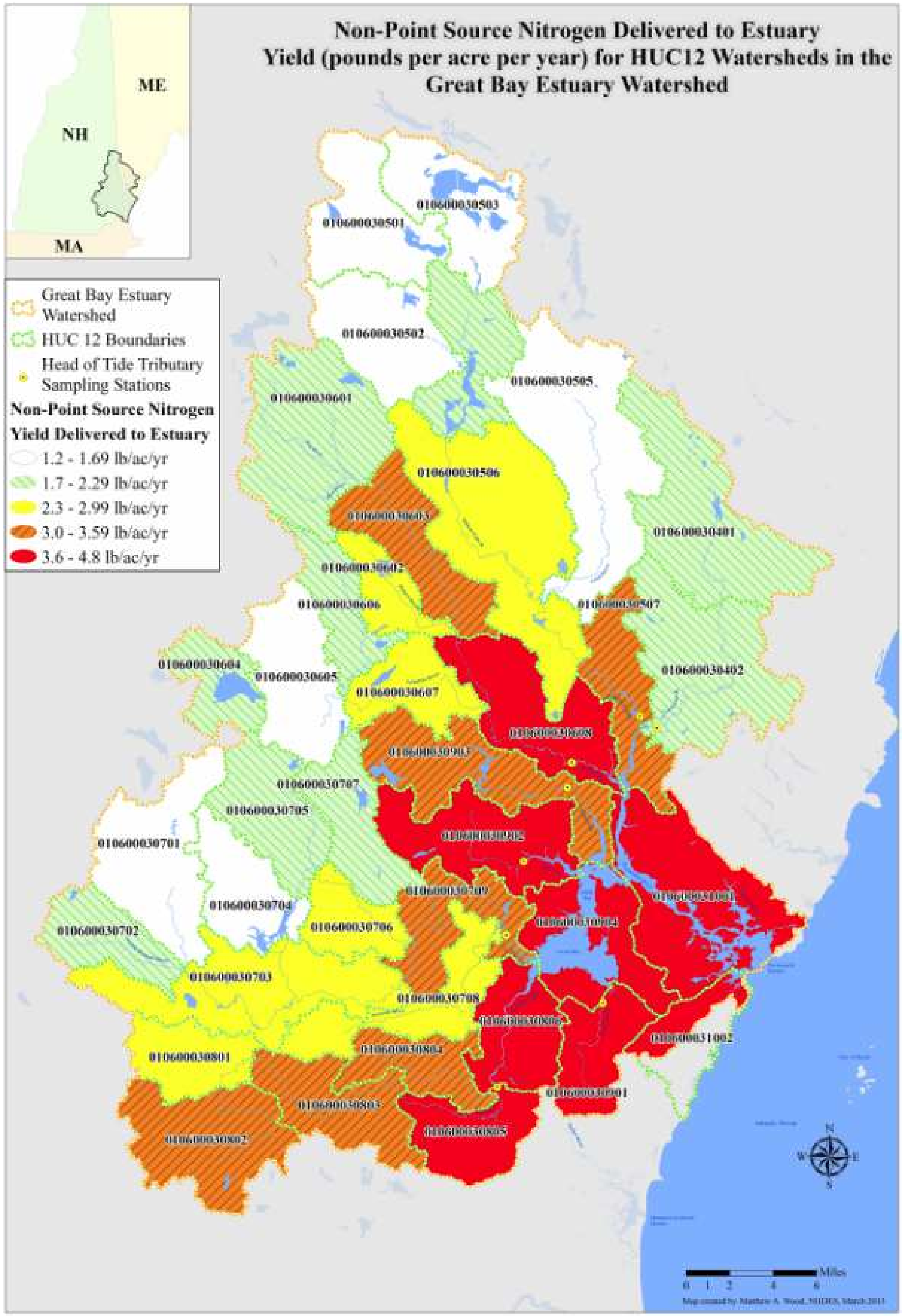


Figure 9: Percent of Non-Point Source Nitrogen Load from the Four Non-Point Sources in Each of the Major Watersheds Draining to the Great Bay Estuary

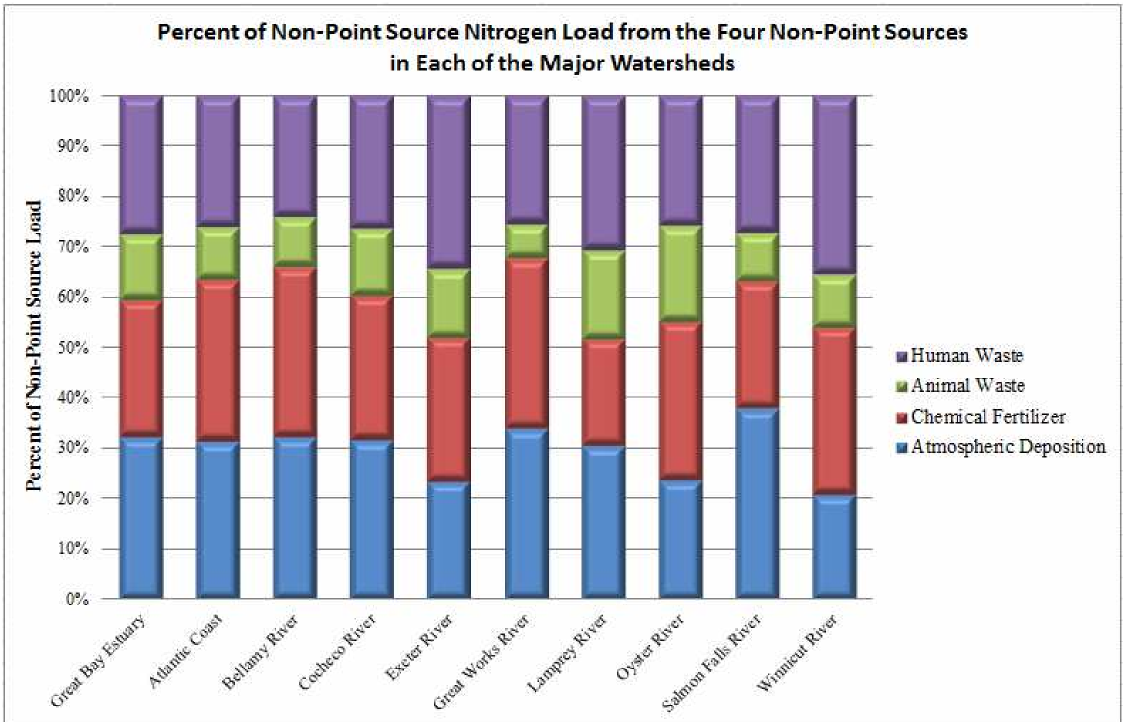
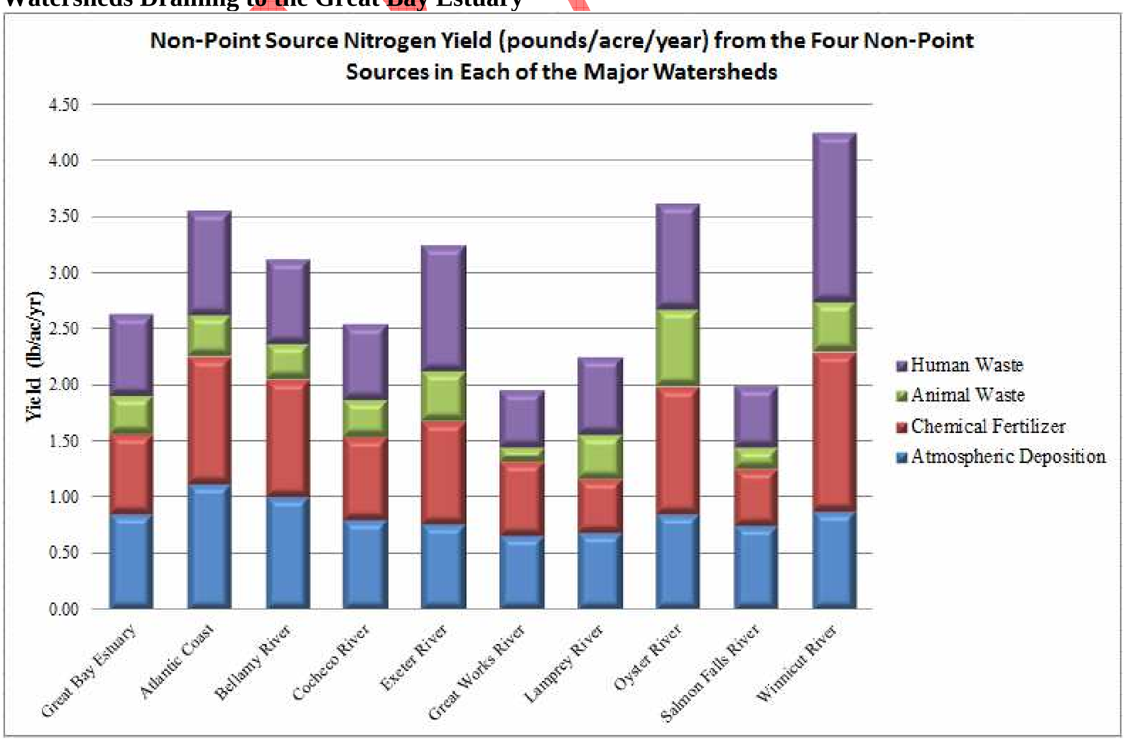


Figure 10: Non-Point Source Nitrogen Yield from the Four Non-Point Sources in Each of the Major Watersheds Draining to the Great Bay Estuary



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